ARS SPECIAL REPORT

MAKING THE MOST OF WET CORN

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SUMMARY

The question of how to make the most of wet corn is becoming an increasingly important one in the farm economy because of a number of technological developments.

Although field shelling still accounts for only 4 to 5 percent of the total corn crop harvested for grain, this method of harvesting is increasing rapidly and promises to have a tremendous impact on corn production. A comparatively recent development (mostly since 1954), field shelling requires mechanical drying facilities or sealed storage for handling the shelled grain.

Other, long-term trends that have contributed to the growing importance of wet corn include: (1) The increased availability and improvement in equipment for drying and storing high-moisture corn; (2) farm mechanization--particularly the swing to mechanical harvesting which puts a premium on early harvest to obtain maximum yields; (3) higher yields from hybrids requiring a long growing season.

Drying as ear corn by natural ventilation--either in the field or in the crib--is still the method used to condition most of the corn crop for storage. (Only 3 percent of the corn harvested for grain in 1956 was mechanically dried.) But a variety of other possibilities are now open to growers, including: Harvesting the corn at a high moisture content either as shelled or ear corn and drying it mechanically with unheated air, supplemental heat, or heated air; or storing the corn without drying in sealed (airtight) storage facilities.

Complicating the farmer's choice of solutions to the wet corn question are the many decisions that need to be made well in advance of putting them into effect. For example, a grower may want to change from conventional methods of picking the corn at around 20-percent moisture content and crib drying it to harvesting the corn wet and drying it mechanically. In order to do this, a grower would have to start making his plans and preparations soon enough to have the new facilities for harvesting and storing the grain ready by harvesttime.

Because of the many variables involved, no single set of "best" answers to the wet corn question can be offered that will apply to all farmers. Size of farm, whether the corn is grown for livestock feeding or sale, drying and storage facilities available, climate, and market conditions are only some of the variables that would affect the answer.

However, enough precise information about the changes that take place in the corn under varying conditions, and the principles underlying them, have been developed through experience and research to guide the individual farmer in determining the best answer to his wet corn problem.

Information for this report was provided by the Agricultural Engineering Research Division, the Animal Husbandry Research Division, the Farm Economics Research Division, and the Crops Research Division of the Agricultural Research Service, and the Market Quality Research Division, the Grain Division, and the Agricultural Economics Division of the Agricultural Marketing Service.

MAKING THE MOST OF WET CORN

For purposes of this report, the term wet corn is used to describe corn with a moisture content high enough to cause a problem in harvesting, handling, drying, or storage. Since the safe moisture level is different under different circumstances, the term wet corn is a variable one. For example, ear corn at a 20-percent moisture level would not be considered wet for purposes of crib drying in most parts of the country, but shelled corn with a moisture content above 13 percent would be too wet for extended storage in conventional bins in the Corn Belt and might be too wet for storage at moisture levels above 10 or 11 percent in some warm, humid areas of the South because of the greater insect problem there.

INCREASING IMPORTANCE OF HIGH-MOISTURE CORN

Technological advances in the growing, harvesting, and storing of corn during the past quarter of a century have magnified the importance of wet corn in the farm economy: (1) by increasing the volume of corn harvested at a high moisture content, and (2) by providing growers with new opportunities for increasing their returns from wet corn.

The rapid increase since 1954 in field shelling of corn at a high moisture content is only a continuation of the gradual but far-reaching changes in corn production that have added new dimensions to the old question: How to make the most of wet corn?

Although field-shelling equipment was invented some 30 years ago in Australia, its adoption and development in this country was retarded until comparatively recently by lack of mechanical drying facilities because mechanical drying is usually required to condition field-shelled corn for storage. Field shelling still accounts for only a small percentage of the total corn crop harvested for grain (probably between 4 and 5 percent in 1958). However, the practice promises to grow in importance as old harvesting machinery is replaced and as mechanical drying equipment becomes more available and better known. Savings in storage space and labor[1] are prominent among the reasons for changing to field shelling listed (in an Illinois survey) by the growing number of large-scale growers who are adopting the practice. (See page 9.)

Successful use, by livestock growers in some areas, of airtight structures for storing wet corn (either shelled or as ground ear corn) without drying is another comparatively recent development. Use of this

[1]A bushel of corn as unhusked ears varies widely in volume but on an average occupies from 2-1/2 to 3 times the space needed for a bushel of shelled corn. By combining harvesting and shelling in a single operation, field shelling enables the grower to save the extra labor required in handling the grain when it is harvested as ear corn and shelled at a later time. Also, as compared to ear corn, shelled corn flows more readily--hence is easier to handle manually and is better adapted to mechanical feeding.

type of storage (commonly referred to as sealed storage) is largely limited to stockmen growing corn for farm feeding because: (1) There are no established market channels for handling grain stored by this method; and (2) the corn spoils soon after being removed from sealed storage and exposed to air unless it is dried promptly.

Among the long-term developments that have tended to give wet corn a more prominent place in the farm picture are:

- The tendency toward widespread use of high-yielding varieties with a long growing season. This practice has both increased the total corn crop and the probability of corn with a high moisture content at harvest-time.

- The high percentage of corn for grain harvested mechanically now as compared to earlier decades. About 80 percent of the U. S. total was harvested mechanically in 1956 as compared to only 12 percent in 1938. Farmers with mechanical pickers or field-shelling equipment have an incentive to harvest their corn with a high moisture content in order to get the maximum yield from their acreage. When corn is harvested mechanically, field losses due to shelling and lodging increase sharply after the corn has dried below 22-percent moisture content.

- Improvement and increased availability of mechanical drying equipment which enables farmers to condition wet corn for safe storage on the farm, to assure that it is marketable as dried shelled corn, or to meet requirements for storage under the Commodity Credit Corporation loan program.

Complex Choices Involved in Handling Wet Corn

A complex series of interlocking choices is involved in determining the way growers handle the wet corn question from planting time, through harvest, to ultimate disposal of the grain through sale or feeding: Should they risk planting a high-yielding hybrid with a long growing season, or settle for a lower yielding hybrid that matures more quickly? Should wet corn be left in the field to dry on the stalk or in the shock--or be harvested with a high moisture content? What method of harvesting is best in a particular instance--harvesting the corn with a mechanical picker or with field-shelling equipment, or handpicking it, either from the stalk or shock? If the corn is harvested with a high moisture content, the question then is whether to sell the wet corn at a discount (assuming it is salable), or to keep it and depend on natural drying, or to dry the corn mechanically for storage or sale. If the decision is to dry mechanically, the choice is between in-storage drying, with unheated air or small amounts of supplemental heat, or heated-air drying (usually shelled and in batches). Or the question may be whether or not some other method of storing or using the wet corn would be the best solution, such as: Cutting the whole plant for silage, storing the ground ears or shelled grain without drying in airtight storage facilities, or using the corn acreage as livestock forage.

The final choice of methods for dealing with the wet corn question is further complicated by the fact that many choices--by their nature--have to be made in advance of going into effect, and some involve longtime investment in equipment and buildings.

The choice between a long-season hybrid and an early-maturing one is made when growers purchase their seed--normally well in advance of planting. If planting is unduly delayed by unseasonable weather or other circumstances, growers who normally plant a long-season hybrid may consider switching to a short-season one. But in actual practice the possibility of a last minute switch in planting choices is likely to be limited by the fact that growers already have purchased their seed corn--or because the supply of short-season hybrid seed on the market is inadequate.

The decision for or against changing from field drying to mechanical drying also needs to be made early. Buying and installing a drier requires time as well as considerable investment; and custom-drying facilities at present are likely to be insufficient to meet the demand in wet years.

No One Answer to Wet Corn Question

Because of the many variables involved, there is no single set of "best" answers to the wet corn question that would apply to all farms. Weather conditions prevailing in a particular area affect the type of drying facilities needed. Size of the corn acreage on a farm is an important consideration in deciding what harvesting or storage facilities would be most efficient and economical. Whether the corn is produced for feeding on the farm or for cash sale may be the determining factor in deciding for or against a particular method of harvesting, drying, or storing the corn. Or equipment and buildings owned by a grower or available to him could be a major consideration.

In order to make an informed choice regarding the possibilities of handling wet corn, precise information about the changes that take place in corn of varying moisture contents when subject to varying conditions is needed. Although there are still gaps in our knowledge, enough research-developed facts are available to guide a grower in selecting and following through with the method of handling wet corn best suited to his particular needs.

Any one of several methods of conditioning wet corn for storage or other disposition can provide a complete solution theoretically and actually to the wet corn question. Each has its advantages and limitations. The important question facing growers in choosing among possible solutions is not whether this or that method will work. The key question is: What method will give me the maximum net return in the particular locality where I farm and under my set of circumstances?

SOME MAJOR CONSIDERATIONS INVOLVED IN HANDLING WET CORN

The most important single factor affecting the keeping quality of corn in storage is moisture content. Other conditions being the same, any increase in the moisture content of corn above safe storage levels accelerates mold growth and consequently the rate of spoilage.[2]

[2] This general rule applies only to storage as dry grain. In sealed storage, when wet corn is stored in airtight facilities, a relatively high moisture content (23 percent or higher) is required for safe storage.

A number of other factors also have an important effect on the keeping quality of corn during drying and in storage, however. Temperature, relative humidity, mechanical damage, insect infestation, presence of husks, silks, and other foreign matter in the corn, and rate of airflow through the grain (whether by natural ventilation or forced air) all influence the rate at which molds and fungi grow in harvested grain.

SAFE MOISTURE LEVEL VARIES WITH CIRCUMSTANCES

The paramount effect of moisture content on the keeping quality of grain raises the basic question: What is a safe moisture content for corn in storage? This question does not have one answer but several different answers depending on the circumstances.

In general, the grain needs to be drier if it is kept for long periods or in areas where the weather is warm and humid, or where insects are a particular problem. Also shelled corn needs to be drier for safe storage than ear corn.

Moisture Level for Crib Storage of Ear Corn

The top recommended moisture content for picking ear corn for crib drying and storing in the United States is around 20 percent.

Moisture Levels for Storing Shelled Corn[3]

For Extended Storage in Conventional Bins

In the Northern States, shelled corn should be dried to a moisture content not exceeding 13 percent for extended storage (for more than a year).

In the Southern States the "safe" moisture level for extended storage is slightly lower--12 percent is recommended in the mountain regions of Virginia and Georgia, for example, and 10 or 11 percent in the low coastal areas.

For Short Periods of Storage in Conventional Bins

In the Northern States, corn shelled for feeding during the winter months can be stored at 15- to 16-percent moisture content without much risk, but if the corn is kept into the warm weather season, the grain should be dried to around 13 percent, or at least to 14 percent.

[3] To meet the requirements for a Commodity Credit Corporation loan on grain held in storage, shelled corn needs to be dried to 13.5 percent moisture. In some cases, particularly in wet years, applications for CCC loans have to be turned down because the grain does not meet moisture-content requirements.

For Sealed Storage in Airtight Structures

When high-moisture corn (either shelled or as ground ear corn) is stored without drying in airtight structures, the grain should have a moisture content of not less than 23 percent. If ordinary silos are used, the minimum recommended moisture level is higher (around 25 percent).

Moisture Levels for Protecting Stored Grain from Insect Activity

In areas where insects are a problem, over-drying[4] the corn may be advisable for safe storage. When shelled corn is maintained in storage at 9-percent moisture content or below, the grain is relatively safe from insect activity. For practical purposes, however, farmers who are trying to control insect activity by over-drying their corn usually dry the grain to around 10 to 11 percent with good results. Some farmers object to corn dried to these levels because livestock do not like it as well as corn of a higher moisture content. This objection can be met by taking a small quantity of the grain out of tight storage far enough in advance of feeding for it to reabsorb moisture from the air. However, on the basis of present evidence from feeding trials, it appears that although animals seem to prefer corn with 13 percent or more moisture content, they will eat the drier corn without any apparent effect on their gains.

Moisture Level for Immediate Sale as U. S. No. 2 Corn

When drying for immediate sale as U. S. No. 2 grade corn, farmers usually aim at 15.5 percent--the top moisture content permitted for this grade corn. Drying beyond this point has the effect of reducing the quantity of corn the farmer has to sell. On the other hand, when the moisture exceeds 15.5 percent, grain is subject to a moisture discount--and may even be unsalable in wet years when the market is glutted.

MEASURING MOISTURE CONTENT

Corngrowers need to be able to measure the moisture content of their grain with a reasonable degree of accuracy. Failure to do so can result in heavy loss, because of the important influence that moisture content has on harvesting efficiency, drying requirements, storage safety, and market value of the corn.

With experience in harvesting and drying grain a grower may be able to estimate the moisture content. But putting too much dependence on a guess--even a trained one--can be risky, particularly if the corn is not uniform in moisture.

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[4] Over-drying is the term commonly used to describe the practice of drying corn below 13 percent, the moisture level recommended for extended storage in the Corn Belt. However, some grain storage experts object to the term as implying that grain dried below 13 percent has been dried too much--when, in fact, it has been properly dried for maintaining its quality in areas requiring moisture levels below 13 percent for safe storage.

Usually instruments for measuring the moisture content of corn are available at local elevators. But any method of measurement is subject to error if representative samples are not provided or if the readings are not properly interpreted.

In choosing samples from the field for testing, it is important to get representative samples. Since appearances are likely to be deceptive as a basis for selecting a typical ear, the recommended approach to the problem is for farmers to sample ears by a predetermined system--every 20th ear in a row, for example--instead of walking through the field and picking ears that <u>seem</u> to be typical.

When a sample is taken from grain that is being dried <u>in storage</u>, care should be taken that moisture content of the wettest grain is measured--rather than the average moisture content. The percentage of moisture contained in the wettest grain determines whether or not the corn has dried to a safe level. To get a representative sample of grain dried in bulk, access to the grain in different sections of the bin--either by openings or by a grain probe--is necessary.

In using an instrument that measures moisture content of the grain by its resistance to an electric current, growers may be led to think that corn is drier than it actually is, if the test is made while drying is going on or has just been completed. This is due to the fact that kernels dry unevenly and the outside surface would be drier and consequently offer more resistance to the electric current immediately after drying than if the test were made later when the moisture was redistributed evenly throughout the kernel.

HARVEST DECISIONS

When corn approaches maturity--at different times according to variety, region, and weather prevailing in a particular year--growers are faced with important choices related to the wet corn question. These choices center around two major harvesting decisions: (1) When to harvest; and (2) what method of harvest to use.

When to Harvest

<u>Advantages of Early Harvest</u>

Among the broad general considerations favorable to harvesting the grain as soon after it matures as practicable--high moisture content notwithstanding--is the fact that the longer the grain is left to dry on the stalk after it matures, the larger the field losses due to lodging, dropping of ears, or shelling are likely to be.

Also in some areas where insect pests are a particular problem, a late harvest increases the hazard of insect damage to corn, both in the field and in storage. Corn borers attack grain in the field, weakening the stalk. This may cause severe lodging and result in heavy harvest losses, especially in late-harvested grain. The Angoumois grain moth and rice

weevil are storage pests. However, in warm areas where they survive the winters, these insects may infest mature corn in the field and later cause serious damage to the stored grain.

Early harvest also helps farmers who rotate their corn acreage into other crops to minimize the weed problem posed by volunteer corn. Farmers growing soybeans or other crops following corn sometimes find that their worst weed is volunteer corn, which has to be removed with considerable labor and expense. A late harvest normally results in more corn dropped in the field due to lodging and shelling--hence increases the probability of a heavy infestation of volunteer corn.

When a cover crop is grown immediately following corn, an early harvest enables farmers to get an early start on the second planting.

Disadvantages of Harvesting Corn with High Moisture Content

Chief among the considerations unfavorable to harvesting corn with a high moisture content is that wet corn is more susceptible to deterioration than corn that has dried to a safe level. Wet corn is likely to spoil or be seriously damaged before it is used unless it is properly conditioned by drying or is stored wet in airtight structures.

Picking wet corn therefore involves investment in equipment for drying or storing the grain in airtight structures, as well as the labor and power costs involved in these procedures. The higher the moisture content above safe storage levels of the grain when it is harvested, the more moisture it will be necessary to remove in a given time to avoid serious damage--and consequently the greater drying capacity and the larger the power requirements for conditioning the grain. For example, to reduce the moisture content of a bushel of shelled corn from 28 to 13 percent requires the removal of 11.4 pounds of water; from 21 to 13 percent, only 5.5 pounds of water.

The danger of mechanical damage to the kernels in harvesting shelled corn is increased if the moisture content of the grain is excessively high. Shelling at a moisture content above 25 to 28 percent is not advisable.

Method of Harvest

Trend Toward Mechanized Harvest

As regards what method of harvest they will use, a large percentage of farmers have already decided in favor of mechanization. In 1956 about 80 percent of the corn harvested for grain in the United States was mechanically harvested. The percentage varies widely by regions, from nearly all the crop in the Corn Belt to a relatively small part of it in the Delta States--Mississippi, Arkansas, and Louisiana. No State reported less than 15 percent of the grain corn harvested mechanically in 1956, however.

Of particular relevance to the wet corn question is the rapid increase in field shelling during the past several years. The Agricultural Research Service estimates that by the end of 1958 about 25,000 field-shelling units (including both field shellers and combines with field-shelling attachments)

were in operation on American farms as compared to around 3,500 at the end of 1955. Assuming that each unit harvested an average of 150 acres, between 4 and 5 percent of the corn acreage harvested for grain in 1958 was field shelled. Since mechanical drying or sealed storage is necessary for safe handling of field-shelled corn in most areas of the United States, the growing trend toward field shelling has increased the dimensions of the wet corn question.

Pros and Cons of Mechanized Harvest

Important among the considerations that have led to the wide adoption of mechanical harvesting equipment are the savings in labor and time which they provide. The United States Department of Agriculture estimates that field pickers have enabled farmers to harvest an acre of corn in 2.6 hours compared with 6.4 hours when the corn is picked by hand and more than 24 hours when the corn is husked from the shock.

Weighed against the advantages of mechanical harvesting are the cost of the equipment, high field losses,[5] and mechanical injury to the corn which can result when mechanical pickers or field-shelling machinery are operated under adverse conditions, are adjusted improperly, or are operated at excessive speeds. (See section on "Adjustment and Operation of Harvesting Machinery," page 9) for discussion of relation of moisture content and other variables to yield and mechanical damage in harvesting.)

Pickers Versus Field Shellers

In weighing the advantages of using mechanical pickers as compared to field-shelling equipment for harvesting their corn crop, various considerations will affect different farmers in different degrees. For example, the type of equipment that will do the job most efficiently and cheaply will depend on the size of the farm, drying and storage facilities available, and the climate of the area in which the farm is located. It will depend also on picking equipment already owned and its condition of repair.

One advantage of mechanical pickers is that they can harvest grain for either crib drying or mechanical drying. Also they can harvest grain at a higher moisture content without severe mechanical damage than can field-shelling equipment. Ear corn can be picked at a moisture level of 30 percent or more without excessive mechanical damage. The top recommended moisture level for field shelling to avoid severe mechanical damage to the grain in harvesting is from 25 to 28 percent.

Among the advantages offered by field shelling is that this method of harvest enables farmers to reduce field losses by early harvest and saves storage space (by eliminating the cobs) and labor. (Harvesting and shelling are accomplished in one operation, shelled corn is easier to handle, and the bother of hauling cobs from the farmyard is avoided.) Also where insects are a problem, field shelling and drying enable

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[5] Wide variation in field losses in mechanical harvesting is underlined by a check by the Illinois Agricultural Experiment Station of 24 machines participating in a harvesting contest in 1950. The losses in corn dropped by the 24 machines ranged from 5.5 to 25 bushels an acre in a cornfield that averaged 80 bushels per acre.

farmers to cut losses from the rice weevil and other pests by harvesting early and storing the dried corn in tight bins. This permits fumigation to destroy pests already in the grain or those that may infest it during storage and keeps birds and rodents from getting access to it.

Chief among the considerations limiting the use of field shelling is that under weather conditions prevailing in the United States the corn cannot be expected to dry to the moisture content required for safe storage without mechanical drying. Consequently, the additional cost of mechanical drying facilities and power for operating them is generally necessary for field shelling. Also, field shelling can result in serious mechanical damage to the grain if the corn is harvested at a moisture level in excess of around 28 percent.

Break-Even Point For Change-Over to Field Shelling

Because the fixed costs are higher per bushel when a small rather than a large number of bushels are to be dried, farmers with a large corn acreage would be more likely to find field shelling and drying advantageous. In Illinois, for example, a cooperative study by ARS and the State Agricultural Experiment Station comparing costs and returns from field shelling and drying with conventional machine picking and storing indicated that at prices then prevailing in that State (during 1954), a corn-grower would need to handle a minimum of 5,800 to 7,500 bushels of corn annually before he could expect a shift in harvesting methods to pay for the higher investment involved in field shelling.

Storage considerations (the need for additional storage, the necessity for replacing wornout cribs, and higher cost of storing ear corn) were rated first among the reasons for changing from mechanical picking to field shelling by the greatest number (79 percent) of farmers questioned in the Illinois study. Labor saving afforded by field shelling was listed by 35 percent of the farmers as a reason for adopting this method of harvest.

Adjustment and Operation of Harvest Machinery

Importance of adjusting and operating mechanical harvesting equipment properly, and of weighing effects of moisture content of the corn and other variables on harvesting efficiency in using various types of equipment, is stressed by numerous studies and borne out by the general experience of farmers.

Moisture Content Affects Harvesting Losses

Studies, recently conducted in Georgia, bear out findings from other parts of the country indicating that harvesting field losses tend to increase when the corn has dried below 22 percent at harvest. These studies were conducted by the Georgia Agricultural Experiment Station in cooperation with ARS using mechanical pickers and grain combines with sheller attachments. A breakdown of the field losses when corn was harvested at various moisture levels is shown in table 1.

Table 1.--Percent of Lodging and Corn Harvesting Losses for Corn Harvested Mechanically[1] at Different Levels in Georgia

Moisture level	Lodging	Corn loss		Total loss
		Ear loss	Shelling loss	
	Percent	*Percent*	*Percent*	*Percent*
28-30 percent	9.9	1.9	4.1	6.0
22-28 percent	9.9	2.1	3.9	6.0
18-22 percent	12.3	3.6	4.9	8.5
15-18 percent	23.0	6.3	2.6	8.9

[1] Harvesting data for this study were compiled over a 3-year period. During the first 2 years the corn was harvested with a picker husker and in the last year with a grain combine equipped with a sheller attachment.

Studies conducted by the Illinois Agricultural Experiment Station in cooperation with ARS also point up the tendency of field losses to increase when harvesting is delayed too long. It was found, for example, to get any yield advantage from field shelling their corn, farmers would need to shell it at a moisture content in excess of 22 percent.

The Illinois study also found that the chances of salvaging--either by handpicking of lodged or dropped ears or by livestock feeding--corn left in the field following field shelling were also greater when the harvest was early. This is because a late harvest increased the probability of bad weather and consequently the chances that dropped grain would become imbedded in the dirt.

Since the great majority of farmers still depend on crib drying to condition corn for storage and consequently harvest their corn at moisture levels of 20 percent or less, the clear inference from these and similar studies is that millions of bushels of grain are lost by American growers every year because the harvest is delayed until the moisture level reaches the levels required for safe cribbing.

Moisture Content Affects Susceptibility to Mechanical Damage

When corn is harvested with field-shelling equipment at moisture levels above about 18 percent, the chances of mechanical damage increase as moisture rises. ARS recommends against field shelling corn at a moisture content above 25 to 28 percent whenever possible because mechanically damaged kernels are more subject to mold and insect attack. Also, corn grown for sale is subject to downgrading and price reduction if mechanical damage is excessive.

Farmers with a large corn acreage to harvest with limited field-shelling equipment are frequently faced with a difficult choice between: (1) going into the field when the moisture content of the grain is around 30 percent; or (2) delaying harvest until the moisture level is around 25 to 28 percent and running the risk of not completing the harvest until the last corn harvested has dried below 22 percent moisture content. In such a situation, ARS research engineers feel that growers should consider the advantages of sacrificing some of the yield in order to stay out of the field until the moisture content of the corn drops to around 25 to 28 percent.

Many Variables Affect Harvesting Efficiency

In addition to moisture content, a number of other variables affect harvesting efficiency. For example, harvesting losses increase sharply when equipment is operated at excessive speeds. Also, harvesting efficiency is affected by weeds, by the time of day, and by the weather. How well the harvesting machinery is adjusted to meet varying conditions also has an important effect on harvesting efficiency.

Proper Adjustment of Harvesting Machinery Important

Importance of proper adjustment of harvesting equipment to get maximum yields, avoid mechanical damage to the corn, and to assure clean grain is emphasized by agricultural research engineers. Following manufacturers' instructions for adjusting and operating the harvesting equipment to meet varying moisture and other conditions will help growers harvest their corn efficiently.

CHOOSING AMONG METHODS FOR HANDLING AND DISPOSING OF WET GRAIN

When the moisture content of harvested corn is too high for safe storage in regular bins, a grower may follow one of a number of courses--all aimed at getting the maximum return from wet corn. Livestock feeders and farmers who grow their corn for cash sale run widely different types of farming operations--so are likely to choose different methods of handling and disposing of high-moisture corn.

A livestock feeder may: (1) Dry his wet corn in the crib, (2) dry it mechanically, (3) store it wet in airtight structures, (4) store it as-is in quantities no larger than can be used for feeding before it spoils, or (5) sell at a discount and buy feed corn as needed for the livestock.

A commercial grower may: (1) Sell his wet corn immediately as ear corn at a discount or (2) dry it for immediate or later sale.

SELLING CORN WET--METHOD USED BY SOME GROWERS

Wet Corn Not Always Salable

Some cash growers make a general practice of selling their corn from the field--and consequently do not have facilities for storing or conditioning their corn on the farm. In wet corn years, however, a farmer who grows his corn as a cash crop for quick sale may find the market glutted with high-moisture corn and consequently be unable to sell it. Therefore every grower is potentially concerned with the possibilities and problems of conditioning and storing high-moisture corn on the farm.

DRYING MOST COMMON METHOD OF HANDLING WET CORN FOR STORAGE ON FARM

Drying--either by natural ventilation or with forced air--is the only practical method[6] that has been found for conditioning high-moisture corn for farm storage in conventional bins.

Four General Methods of Drying

Four general methods are used for drying grain on farms: (1) Drying by natural ventilation--as in the crib or in the shock; (2) drying mechanically with unheated air (usually in-storage drying); (3) drying mechanically with unheated air supplemented by small amounts of heat (10° to 20° F. above the atmospheric temperature); (4) drying with heated air.

Each method has its advantages and limitations. One method may be preferable in one instance and another method of drying may be a better choice--or perhaps the only practicable way to condition grain open to a farmer--under another set of circumstances.

DRYING METHODS VARY--BUT HAVE SAME OBJECTIVES AND ARE GOVERNED BY SAME PRINCIPLES

In drying high-moisture corn, the objective of growers is to condition the grain for safe storage at a minimum of cost and without significant damage to the grain.

Although facilities and procedures for drying by different methods vary rather widely, a number of general drying principles are common to all of them. Failure to take into account all the principles involved can result in inefficient drying or serious damage to the grain. Therefore a working knowledge of the major drying principles is basic for intelligent selection and efficient use of drying equipment to get maximum returns.

A summary of some of the major drying principles and other related factors that growers need to take into account in selecting and using any of the various methods of drying corn for storage is presented in this section.

Advantages and limitations of particular methods of drying and problems especially associated with the different methods are presented in subsequent sections.

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[6] To date experiments in treating grain with preservatives or drying wet corn by other means than circulating air have not developed any practical alternative to farm drying by natural or mechanical ventilation.

Elevators mix (blend) lots of wet grain with dry grain so that the high-moisture corn will be dried through the process of absorption by the drier kernels. This method of drying is generally not practical on farms, however.

General Requirements for Successful Drying

Successful drying requires that the grain is dried (1) to a safe moisture level, (2) before significant damage takes place, and (3) by a method that will not cause serious mechanical injury or nutritive loss to the grain.

General Principles Affecting Drying of Corn

Hygroscopic Property of Corn

It is important to understand the hygroscopic property of corn to control the changes that take place in corn during drying and storage. This property means that corn--both kernels and ears--have a tendency to absorb and retain moisture. Under some circumstances, more moisture will be absorbed by the corn from the air and under other circumstances, moisture will be lost to the air. Direction of the moisture movement and rate at which water is evaporated from or absorbed by the corn varies with the moisture content of the corn and the temperature and relative humidity of the air.

The process of drying or absorbing moisture goes on continuously until the corn reaches a point of equilibrium with the surrounding atmosphere, as regards to its moisture content. The critical point at which moisture content of the corn is in balance with the surrounding air varies with the temperature and relative humidity. At a temperature of 70° F., corn with a moisture content of 13.5 percent is in equilibrium with the air when the relative humidity of the air is 70 percent; corn with a moisture content of 10.5 percent, when the relative humidity is 50 percent.

Many Factors Affect Drying

Drying depends on the capacity of air to absorb moisture from wet grain as it moves through the grain. In mechanical drying, air is forced through the grain.

Heat increases the capacity of the air to hold moisture, hence tends to speed up drying. On the other hand, heat--within limits--is favorable to mold growth. Therefore, when corn is dried in warm weather or with heated air, the permissible drying time (i.e. the maximum time before significant damage occurs) is shorter than it would be if the grain were cooler.

The drying capacity of the air varies inversely with the relative humidity. For example, at a temperature of 70° F., a pound of air with an associated relative humidity of 40 percent would be able to absorb 0.0033 pounds of water vapor before reaching the saturation point; with an associated relative humidity of 50 percent, about .0026 pounds; and with an associated relative humidity of 60 percent, .0020 pounds.

Corn with a high moisture content releases moisture more readily than corn that is drier. After the kernels dry to a moisture level of 22 to 23 percent, progressively drier air is required to continue the drying process as the moisture content in the corn approaches equilibrium with the air.

Generally speaking, the time required for drying varies inversely with the rate of airflow. In other words, the faster the air of a given drying capacity moves through the grain, the less time is needed to dry the grain. This principle is limited by the hygroscopic equilibrium properties of corn.

When air is circulated through masses of grain, the grain particles resist the movement of the air. Consequently, the larger the mass of grain to be dried, the longer time it would take the air currents to move through the grain--other factors being equal--and the more time would be required to dry it.

Shelled corn offers more resistance to the movement of air than does ear corn, in part because it packs more solidly with less air space between the kernels.

Corn that has been damaged mechanically is more susceptible to damage when wet than undamaged corn--so the permissible drying time is shortened.

Foreign matter--such as dirt, chaff, or silks--in the grain fills up the space between the ears or kernels. This prevents the air from circulating evenly through the corn, so slows the drying process and may result in the heating and spoiling of wet, unventilated pockets of grain.

Corn Dries on Fronts

When corn in bulk is dried by any method, the grain does not dry as a unit. Rather, the drying proceeds along a definite pattern of drying fronts. The grain that comes in contact with the air as it enters the bin dries first. As the air circulates through the corn, it absorbs moisture from the grain until it reaches a point of equilibrium with the grain, or until it becomes saturated. The capacity of the air to absorb moisture diminishes as it moves through the moist grain for two reasons: (1) The moisture absorbed from the grain increases the relative humidity of the air; and (2) the temperature of the air is reduced by the process of evaporation and this also reduces its capacity to hold moisture. [7]

As a result of the drying patterns set up by the movement of air through the grain, the corn nearest the source of the air may be dried to a safe level--or over-dried--before the grain last reached by the air stream has lost any moisture. Under some conditions, grain near the point where the air leaves the drier may even absorb moisture or be wet by water condensed from the cooling air, before drying is completed. For these reasons, drying grain in storage until the average moisture content of the grain reaches the recommended level for storage is not enough. To assure that the grain will be properly conditioned for storage, drying needs to continue until the drying front has advanced through the grain and the last kernels have dried to a safe level.

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[7] When unheated air is used for in-storage drying, normally the full drying capacity of the drying air has been utilized before it leaves the bin. On the other hand, when corn is dried in batches with heated air, frequently the drying air leaves the drier before its full drying capacity has been used.

Temperature Difference Within Stored Grain Causes Moisture Migration

When grain is stored in bulk, wide variations in temperature in different parts of the bin can result in excessive movement of moisture from grain in one section to grain in another section.

For example, during the fall and winter months, grain near the outside of the bin become colder than that in the center. As a result, the warm air in the center of the bin rises, creating air currents within the stored grain. When the cold air from the sides of the bin comes in contact with the warm grain, it becomes warmer, its capacity to hold moisture increases, and it absorbs moisture from the grain in the center of the bin. As the warm, moisture-laden air rises and comes in contact with the cold grain at the top of the bin, it cools and redeposits some of the moisture that it picked up from the warm grain. This causes the moisture level of the top layer of the grain to increase without any increase in the net moisture level of the stored grain. In fact, a slight net decrease in moisture may take place.

Some moisture migration is normal in stored grain. But excessive migration, caused by wide variations in temperature within the stored grain, can result in serious accumulations of moisture in grain otherwise dry enough for safe storage.

Moisture migration is more likely to be a problem when grain is stored in large lots. This is due to the fact that while the temperature of the grain near the bin wall changes rapidly with the weather, the outer layers of grain in a filled, large bin insulate the grain in the center. For this reason, grain elevators and farmers storing grain in large lots often use low-power fans to equalize the temperature of the stored grain. This process of moving air through stored grain at low airflow rates (for example, 1/10 to 1/50 cubic feet per minute per bushel, abbreviated as cfm/bu.) for other than drying purposes is called aeration.

DRYING BY NATURAL VENTILATION

Advantages and Limitations

Drying by natural ventilation is by far the most commonly used method of conditioning corn for storage.

One of the major limitations of crib drying is the complete dependence of the rate of drying on the vagaries of the weather. As a result, crib drying is not adapted to conditioning ear corn with a moisture content above about 20 percent without considerable risk. Also corn in open cribs is more vulnerable to insect and rodent infestation and to reabsorption of moisture by wetting from rain or snow. As a result, there is a greater risk of damage and spoilage than there is with corn that has been dried mechanically and stored in tight bins.

To make an accurate assessment of the real costs of drying by natural ventilation, any and all losses in yield or deterioration of quality of the grain need to be taken into account. Thus losses in yield resulting from harvesting at 20-percent moisture level would properly be considered a part of the cost of drying by natural ventilation.

Recommended Width of Cribs Varies with Area

In crib drying, farmers depend on the natural movement of the surrounding air through the grain to remove excess moisture before significant deterioration takes place. Since they have no control over the humidity and temperature, they must make the best possible use of natural air movement. One way farmers can do this is to locate the bin in a spot where it will get the maximum natural movement of air. Another way is to make the crib narrow so that the air can pass through it easily.

Since more air is needed to dry corn when the humidity is high, bins should be narrower in humid areas than in dry areas.

MECHANICAL DRYING--SOME PROS AND CONS

Decision for or against the use of mechanical drying equipment depends on the balance between the advantages and the costs of drying. Each particular farm presents a different problem and requires individual management decisions.

Advantages of Mechanical Drying

Mechanical driers enable the farmer to:

Condition high-moisture corn for safe storage; dry wet corn to avoid a moisture discount on cash grain; harvest early to get a bigger yield (by avoiding excessive field losses due to lodging, shelling, and insect damage); shell corn to save storage space and permit easier handling and fumigation against insects; use field-shelling equipment, thereby saving time and labor; save corn in wet years; dry other crops, such as sorghum and soybeans; finish harvest sooner, permitting an earlier start on a second crop; reduce work and expense of weeding volunteer corn on rotated acreage by harvesting early before shelling occurs; obtain possible price advantage from early marketing or holding grain for later market.

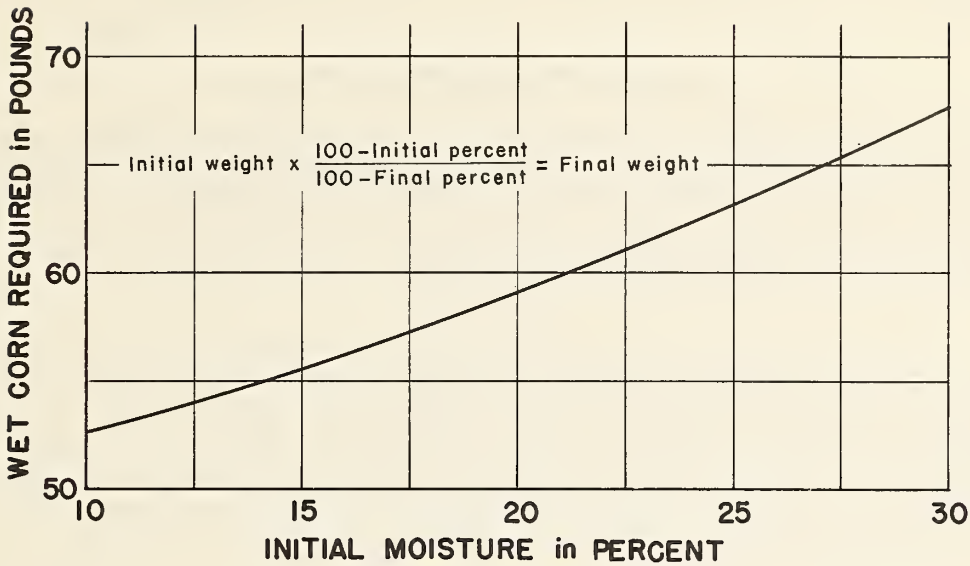
Cost of Drying

Drying costs properly take into account fixed costs such as interest on investment in drying equipment, structures, maintenance, and insurance; additional labor expenses for handling the grain, power and fuel used in drying. Also in drying corn for sale, the loss in salable weight of grain due to drying would be a cost of drying to be measured against gains.

In estimating net gains from drying to the standard of 15.5 percent, growers need to take into account shrinkage resulting from water loss as well as the expense for power and drying facilities. Figure 1 shows shrinkage in terms of pounds of wet corn required to produce one 56-pound bushel at 15.5-percent moisture.

When corn for immediate marketing as U. S. No. 2 grade is dried below 15.5 percent, the shrinkage caused by drying beyond this point represents a net loss to the seller since usually no premium is paid for No. 2 grade corn dried below the standard.

POUNDS of WET CORN REQUIRED to PRODUCE
ONE 56-POUND BUSHEL at 15.5% MOISTURE



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IN-STORAGE DRYING WITH UNHEATED AIR

When corn is dried in storage by mechanical ventilation, drying with unheated air is the method most frequently used. Unheated air (sometimes supplemented by small amounts of heat[8]) is generally considered the medium best adapted to drying grain in storage.

Since drying with unheated air is a relatively slow process, the principal problem is to dry the grain before significant damage takes place.

The length of the drying period is determined by three major factors: (1) Moisture content and condition of the corn at the start of drying (i.e. whether it is shelled or on the cob, the presence of foreign matter, and amount of mechanical damage); (2) drying capacity of the surrounding air; and (3) the rate at which the air is forced through the grain. Since the first two variables are generally governed by local harvest and weather conditions, control of the length of time is almost entirely obtained by varying the rate of airflow.

Airflow and Drying Time

Drying time can be cut by speeding up the airflow. However, power costs go up disproportionately as the rate of airflow is increased. (For example, to increase the airflow from 2 to 4 cfm/bu. requires a 6-fold

[8]See page 19 for discussion of supplemental-heat drying.

increase in power.) Therefore, any unnecessary reduction in drying time through speeding up the rate of airflow will add to the drying costs needlessly. Consequently, the efficient design and operation of an unheated-air drying system will take into account the maximum safe time for drying grain.

Weather and Drying Time

Weather conditions prevailing in an area not only have an important effect on the time required to dry corn mechanically with unheated air, but also affect the maximum allowable drying time. Since heat is favorable to mold growth, difficulties are likely to be encountered in drying with unheated air in hot, humid areas unless the airflow can be increased sufficiently to speed up the drying process.

On the basis of various studies and drying experiments, ARS scientists estimate that the maximum allowable time for drying shelled corn to not more than 15-percent moisture content would range from about 5 days in warm, humid areas in Southern States to about 4 weeks in cooler conditions of the North. These estimates are based on the condition that enough air will be kept circulating through the grain to prevent heating and that drying will be continued, after the corn is dried to the 15-percent moisture level, until it reaches a safe storage level for the area.

Recommended Airflow Rates Vary with Area

Recommended minimum airflow rates for drying corn with unheated air also depend on the effect of weather conditions on drying capacity of the air and on maximum allowable drying time. Table 2 shows how recommended minimum airflow rates vary for different parts of the country.

Table 2.--Minimum airflow rates recommended for drying corn with unheated air in Georgia, Southeast Tidewater areas and under average U. S. conditions[1]

Corn	Initial grain moisture	Minimum airflow rate, cfm/bu.		
		Georgia	S. E. Tidewater	Average U. S. conditions
Shelled	25	6	14	5
	22	5	9	3
	18	3	4	2
	15	2	2	1
Ear	25	8	8	5
	18	4	---	3

[1] From studies conducted by the Indiana State Agricultural Experiment Station, 3 cfm/bu. appears adequate for drying shelled corn from 25-percent moisture in moderate fall weather. In Nebraska the State Agricultural Experiment Station recommends 2 cfm/bu. minimum for clean, sound grain. Maximum permissible moisture content at start of drying was determined by upper moisture limit for harvesting the grain without serious mechanical damage. (See section entitled, "Moisture Content Affects Susceptibility to Mechanical Damage," page 10.)

Continuous Vs. Intermittent Fan Operation

The fact that the drying capacity of unheated air varies inversely with its relative humidity raises the question of whether the fan should be operated continuously in drying or only when surrounding air conditions are favorable.

Continuous fan operation, regardless of weather conditions, so long as the moisture content of the grain is above 15 to 17 percent is the general recommendation of ARS. Studies have indicated that the extra trouble and expense of turning the fan on and off with changes in humidity often offset the slight saving in power costs from intermittent operation.[9]

As the grain moisture content approaches equilibrium with the average relative humidity of the surrounding atmosphere (when the moisture level of the corn reaches 15 to 17 percent in most areas), intermittent operation of the blower may be desirable.

Intermittent operation is obviously more likely to apply to areas in which the relative humidity is high much of the time than to areas where the relative humidity is generally low. In Nebraska where the humidity is low, for example, continuous blower operation is recommended until the final moisture content is reached, except when rainy periods occur during the drying period. In Georgia, cooperative studies by ARS and the State Agricultural Experiment Station indicate that under conditions prevailing in that State many growers who dry with unheated air find it advantageous to shift to intermittent operation after the corn moisture level has reached 16 percent, operating their fans only during the drier part of the day (when the relative humidity is below 70 percent). When intermittent drying is used, a humidistat to provide automatic control of the fan is likely to be a good investment, the Georgia studies indicate.

IN-STORAGE DRYING WITH SUPPLEMENTAL HEAT

Supplemental-heat drying systems are constructed along the same basic lines as systems for drying grain in storage with unheated air except that facilities are provided for introducing a small amount of heat into the air stream.

Supplemental heat is used to speed the drying process and to make it possible for drying to continue when the atmospheric relative humidity is too high for systems using unheated air alone. The basic principle behind the use of supplemental heat is the same as in heated-air drying--that the capacity of the air to hold moisture rises as the temperature is increased. The difference between the two types of systems is essentially that supplemental-heat drying is done in a storage bin and heated-air drying is done in a batch-drying compartment.

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[9] During long rainy periods when the relative humidity is so high that there is little chance of drying, continuous blower operation may be uneconomical, even when the moisture content of the grain is at a high level. However, even during rainy weather the blower must be operated intermittently to remove accumulated spontaneous heat from the grain.

When corn is high to medium in moisture content (above 15-percent moisture level), the blower should be turned on even during rainy weather for at least 15 minutes every day in Northern States and for two or three 15-minute periods each day in Southern States. If the air blown out of the grain during these cooling periods feels appreciably warm, it is a sign that more frequent and longer periods of fan operation are required.

In a supplemental-heat system, enough heat is used to raise the temperature of the incoming air about 15° to 25° F. above the prevailing temperature of the outside air. In contrast, a heated-air system generally operates at delivery temperatures of 140° to 200° F.

A question that rises in weighing the advantages and limitations of using supplemental heat for drying stored grain in a particular instance is: Does the speedup in drying time resulting from the use of small amounts of supplemental heat outweigh the possibility that the added heat may promote mold growth to a point causing significant damage? Evidence from studies conducted to date by ARS and the various States is somewhat conflicting. This is probably due to the different variables affecting the corn at different times and under different climatic conditions.[10] Studies are continuing that will establish general guidelines to aid individual farmers in deciding whether or not supplemental heat would be an asset or a liability for drying under their particular set of conditions. But until more data can be compiled and analyzed, farmers are advised to be guided by local experience and recommendations from their State agricultural experiment stations.

HEATED-AIR DRYING

Pros and Cons of Heated-Air Drying

Among the advantages of heated-air drying are that it dries the grain quickly and regardless of weather conditions, it can be used to dry the wettest grain, and it has a high-drying capacity per fan horsepower.

Disadvantages of heated-air drying include the higher initial equipment costs as compared to in-storage drying with unheated air, fuel costs, some fire hazard, and the considerable supervision required. In addition, the value of the grain for various purposes may be reduced if excessive temperatures are used for drying.

Good Management and Sound Techniques Required for Best Results

Properly used, heated-air drying does a good job of conditioning grain. But with heated-air drying as with other methods, good management and compliance with basic principles for safe drying are necessary for best results. Grain can be damaged if the temperature is raised too high in an attempt to hurry the drying process or if the drier is improperly designed.

Several Types of Heated-Air Systems

Since quick, reasonably even drying of shelled corn is easier to accomplish when the grain is dried in small lots, batch driers with 200- to

[10] In Alabama, for example, the State Agricultural Experiment Station reports that experience has shown that the moist climate in Alabama during the harvest season makes it essential that the drying system be equipped to heat the drying air. In Iowa, on the other hand, studies by ARS and the Iowa State Agricultural Experiment Station showed that drying with supplemental heat shortens the permissible drying time as well as the actual drying time. The conditions under which supplemental heat results in a net gain have not been well defined.

400-bushel capacity are the type most frequently used on farms for this purpose.

When heated air is used for drying larger quantities of grain in storage, the problem is to provide sufficient fanpower to move the air through the grain at a fast enough rate to permit reasonably even drying.

Another type of heated-air drier is the continuous flow system, in which a small stream of grain is moved continuously through the drier so that the grain will all be dried equally. At present this type of drier is not widely used on farms but ARS engineers believe that this method eventually may become the most practical and economical for heated-air drying.

Some Heated-Air Drying Pointers

Overloading Hazardous

Farmers inexperienced in using heated-air driers for corn in storage sometimes overload the drier, because they fail to make proper allowance for one or more of the factors affecting its drying capacity. Important variables affecting the capacity of a drier include: Initial moisture content of the corn; whether it is shelled or on the cob; depth of the grain; the presence of silks, chaff, or other foreign matter in the grain; and temperature of the drying air.

Well known but frequently underestimated is the fact that when corn is harvested at a higher moisture content, the time needed to dry a given number of bushels that the drier can be expected to dry efficiently in one batch is increased.

When heated air is used to dry shelled corn, allowance also needs to be made for the greater resistance to air movement of shelled corn than ear corn. Consequently it is generally advisable to dry shelled corn in thin layers (usually 12 to 24 inches). Ear corn on the other hand can be successfully dried in depths up to 16 feet or more in well designed heated-air driers.

Cleanliness of the grain is another variable that is sometimes underestimated in heated-air drying either shelled or ear corn. Silks, chaff, and other foreign matter in the corn impede the movement of air through it--and therefore may result in nonuniform drying and spoilage unless the volume of grain to be dried or the fanpower is adjusted to compensate.

Increasing the temperature of the drying air speeds up drying but this method of increasing the capacity of the drier is limited because excessive heat damages the grain.

Drying-Air Temperature Guidelines

Both advice and practice with regard to temperature used in heated-air drying vary rather widely.

Because of the many variables affecting the maximum heat to which corn can be subjected without serious loss to its feed value--including

initial moisture content, rate of airflow, and length of heating period--it is impossible to set up one maximum temperature for drying corn for feed which would apply under all conditions. And animal feeding experiments to date by ARS are too limited in range to provide a complete scale of temperature maximums for drying corn under all conditions without significant loss of feed value. However, farm experience and engineering studies have uncovered enough information to provide practical guidance to the farmer.

For farm feeding of livestock, present evidence suggests that drying-air temperatures up to 150° to 160° F. can be used without much damage, assuming that drying is accomplished within 4 hours. Under optimum drying conditions--with low initial moisture content, high airflow rate, and short heating period--temperatures as high as 200° F. probably do not seriously affect the feed value of corn, according to results of recent experiments. (See report on animal feeding experiments, pages 29-30, for a more detailed discussion of the effect of heat and other variables in drying on the feed value of corn.)

For drying seed corn, temperatures above 110° F. should be avoided, since excess heat definitely affects viability of the grain.

For corn that is to be sold to wet millers, heated air above 130° to 140° F. is not advisable. Heat in excess of that temperature tends to break down the starch cells in the corn, making it more difficult to separate starch of the pure quality required by industry with present processing methods. Since there is no quick, reliable, and practical method for determining whether a lot of grain has been subject to excessive temperatures in common use at the present time, wet millers tend not to buy grain from areas with a reputation for drying at high temperatures.

That some farmers are using temperatures far in excess of what they intend is indicated by a management study conducted by ARS research engineers in cooperation with the University of Illinois Agricultural Experiment Station. To avoid damage to their grain that may result from such practice, farmers are advised to install a thermometer in their drier (at a point near where the heated air enters the air delivery chamber) and to make frequent readings.

Cooling Grain Before Storage Important

One essential step that is sometimes overlooked in conditioning wet grain by heated-air drying is to cool the grain to atmospheric temperature immediately after drying. This is important for two reasons: (1) Heat is favorable to mold growth and insect activity; and (2) the moisture migration problem is aggravated when the grain is warmer than the outside air. (Under such conditions, sufficient moisture may accumulate in grain at the top of the bin to cause some caking and molding of the surface grain even though the corn is otherwise dry enough for safe storage.)

The grain can be cooled by turning off the heat and running the fan long enough to reduce the temperature of the grain to atmospheric levels. When batch driers are used, the grain should be cooled before it is moved into storage. The time required to lower the temperature usually varies from one half to one hour.

Management studies emphasize that realistic estimates of drying time for batch drying make adequate allowance for the time required for cooling each batch of grain as well as for loading and unloading time.

When grain is dried in batches it is advisable to mix the grain thoroughly before putting it in permanent storage to help assure an even distribution of moisture. This is particularly important when, due to depth of grain or low rate of airflow, there is a wide variation in the moisture content of the grain coming from the drier.

It is also important that the different batches of grain going into storage be dried to about the same moisture content. Any great variation in the moisture of the grain in different parts of the bin tends to hasten moisture migration from one level to another and can result in heating and spoilage of grain as dry kernels absorb moisture. (When vapor condenses into water, the process evolves heat.)

WET STORAGE

One alternative for handling corn with a high moisture content is to store it wet in airtight storage facilities. If the corn is for farm feeding, this is one of the cheapest ways of storing large volumes of wet corn.

Pros and Cons of Wet Storage

Advantages of sealed storage for high moisture corn (stored at moisture contents above 23 percent) include: Low per-bushel storage cost when large amounts of corn are stored; high feed value and palatability of grain for livestock; ease of handling as compared to ear corn and consequent saving in labor; storage structure also may be used for storing dried grain.

Limitations of sealed storage of high-moisture corn include: Absence of established market channels for selling corn taken from sealed storage; corn stored by this method spoils soon after it is exposed to air (especially in warm weather) unless it is dried; wet corn tends to bridge (that is, pack and arch in a way interfering with the flow) with the result that it does not feed down readily in bins that unload from the bottom; not adapted to self-feeding in warm weather because of susceptibility to heating and spoilage.

Two types of structures are used rather widely for storing corn wet: (1) Hermetically sealed storage such as provided by "glass-lined" silos; and (2) ordinary silos. The former are manufactured and sold in units of various sizes. Ordinary silos are adapted for storing wet grain by sealing the door openings and top surface of the grain with plastic or other impervious material and weighting down to exclude the entrance of air. Where the walls are worn or cracked, it may also be necessary to cover the walls with a protective coating to reduce penetration of air. When ordinary silos are adapted for storing grain, greater weight of the shelled corn must be taken into consideration in determining if walls and foundations can support the increased stress.

When ordinary silos are used, some spoilage near the top is to be expected. In some years more spoilage takes place than in others--1957 was such a year in Iowa (perhaps because it was a warm fall)--but even in such a poor year most farmers contacted by ARS reported they were well satisfied with this method of handling high-moisture corn.

Under emergency conditions, plastic bags or liners are sometimes used in combination with storage structures (such as ordinary bins) for the wet storage of high-moisture corn. The hazard in using a plastic liner or bag is the possibility that air will get in through holes or tears made by nails or other sharp edges.

For storing wet, corn should have a moisture content of 23 percent or more.

In storing grain corn wet, some farmers prefer to grind the whole ear to gain the greater bulk of ground ear corn for feeding. Others store only the shelled kernels to save space. Studies to date have not determined which is more advantageous.

Another unanswered question is how breaking the kernels affects the keeping qualities of corn in sealed storage. It is generally accepted that mechanical damage to the kernels does not seriously affect the keeping qualities of undried high-moisture corn in airtight storage. However, research has not yet shown whether or not breaking the kernels improves the keeping quality of corn in wet storage.

Wet Storage Based on Ensiling Principle

Sealed storage of wet corn is based on the same principle as ensiling. As with regular silage, the growth of molds and other organisms that cause spoilage stops when they have used up all the oxygen in the air. At this point another class of organisms that manufacture their own oxygen take over. These, called anaeorobic, "without air," organisms, react with the grain where there is sufficient moisture to make lactic and acetic acid and produce a product that is nourishing and pleasing to cattle.

ENSILAGE

Advantages and Disadvantages

Another possibility open to livestock growers for handling high-moisture corn is to ensile the entire plant.

When necessary because of a wet year emergency, even very immature corn can be safely stored in this way. Such silage makes a satisfactory feed for cattle but, because of its high moisture content, has a lower feed value per bushel than silage made from more mature corn.

An advantage of this method of utilizing high-moisture corn is that temporary (trench, snow-fence, and stack) silos may be used for salvaging wet corn if permanent silos or other facilities for safely conditioning and storing the grain are not available.

The acreage of corn used for silage has increased 82 percent during the last third of a century despite the fact that the total corn acreage has declined. During the 1952-56 period, about 8 percent of the total corn crop went into silage, as compared to 4 percent during the 1919-21 period.

SOME CORN ACREAGE USED FOR HOGGING, GRAZING, OR FORAGE

Decline in This Method of Using Crop

Another possibility for handling high-moisture corn without resorting to drying or storage is to use the acreage for hogging, grazing, or forage. This method of using the corn crop was much more common a quarter of century ago than it is today. Around 1930, as many as 11 million acres of corn were used for hogging, grazing, and forage, as compared to about one-third that amount in 1956.

The steady decrease in the corn acreage that is harvested in this way reflects the inefficiency of foraging as a way of harvesting the corn crop. It is also in line with the modern trend toward scientific feeding whereby animals are given special rations instead of being left to hunt for their food.

Cost and Income From Various Methods of Handling Wet Corn Compared in Management Studies

Reflecting the importance of wet corn in the present-day farm economy, numerous cost and management studies have been made comparing the various methods of handling. ARS has cooperated with various State agricultural experiment stations--including those in Illinois, Georgia, North Carolina, and Indiana--in a number of such studies.

Results of the various studies are, of course, based on costs, prices, and conditions prevailing in the particular States and years in which the data were obtained. But, with due allowance for price differences and other variables, the studies do indicate the basis on which individual farmers can estimate and compare costs and returns from the various methods of havesting, conditioning, storing, and disposing of high-moisture corn.

The management studies, although prepared at different times and places, all emphasize the fact that direct cash costs and returns from drying are only part of the consideration. Livestock feeders with driers or wet-storage facilities often buy high-moisture grain at sufficient discounts to reduce feed costs, for example. Or, in some instances farmers with limited capital to invest find that although a drier would be profitable, money invested in other equipment might earn more. Again, a grower whose own acreage is too small to warrant purchase of field-shelling and drying equipment may do enough custom shelling and drying to make the investment worthwhile.

Some data from an Illinois study are presented in the following paragraphs to illustrate how cost and income from handling wet grain by various methods compared in a particular instance.

Costs of Wet Storage and Other Methods Compared in Illinois Study

Costs of alternate methods of harvesting and storing high-moisture corn and picking and crib drying ear corn were compared in a recent study conducted by ARS in cooperation with the Illinois State Agricultural Experiment Station. A comparison of estimated costs--based on 1958 prices in Illinois--showed that for farmers handling 6,000 to 8,000 bushels, field shelling the corn at high moisture levels and storing it wet costs less per bushel on an annual basis than other methods. Initial costs for equipment and structures for wet storage were higher, however. At the 6,000 bushel level, the estimated cost advantage in favor of wet storage was: $240, as compared to heated-air drying; $48, as compared to drying with supplemental-heat; and $114, as compared to picking and crib drying as ear corn.

Table 3 is a tabular presentation of the cost estimates with footnotes explaining the basis on which they were determined.

Table 3--Estimated total costs per bushel for field shelling and storing high-moisture shelled corn compared with costs of other methods

(Based on 1958 prices in Illinois)

Item	Bushels of high-moisture field-shelled corn[1]							
	Stored wet in glass-lined airtight bins		Dried with supplemental heat and stored in metal bins		Dried with heated air and stored in stave silo		Bushels of ear[1] corn picked, and stored in wood crib	
	6,000	8,000	6,000	8,000	6,000	8,000	6,000	8,000
	Cents per bushel							
Harvest[2]	11.3	9.4	11.3	9.4	11.3	9.4	9.3	7.7
Haul and unload	2.5	2.5	2.5	2.5	2.5	2.5	3.2	3.2
Dry[3]	---	---	5.7	5.7	10.0	8.4	---	---
Store[4]	10.1	9.4	5.2	5.2	4.1	3.6	6.8	6.3
Shell	---	---	---	---	---	---	3.0	3.0
Field loss[5]	---	---	---	---	---	---	3.5	3.5
Total	23.9	21.3	24.7	22.7	27.9	23.9	25.8	23.7
Difference[6]	0	0	$48	$112	$240	$208	$114	$192

[1] A bushel is defined here as the amount of grain required to yield 56 pounds of shelled corn at 15.5-percent moisture content.

[2] Fixed costs are 14 percent of initial investment--mounted picker, $2,700 and sheller attachment, $700. Operating costs are 3.4 cents to field shell and 3 cents to pick.

[3] Fixed costs are 14 percent of initial investment--burner and fan, $600 per bin for supplemental heat, 2 bins 6,000 and 3 bins 8,000 bushels; batch drier, $3,200; and all systems, $22 per year for fuel tank. Operating costs are 2-1/2 cents per bushel.

[4] Costs of circular metal bins include perforated floor and duct work. Ear-corn cribs are estimated at $4,500 and $5,600 for 6,000 and 8,000-bushel volumes. Space above crib driveway is included as ear-corn storage, not small grain.

[5] A charge of 4 percent of gross yield is made for greater field losses.

[6] Cost differences between wet storage of high-moisture corn and other methods.

INSECT INFESTATION AN IMPORTANT STORAGE PROBLEM IN SOME AREAS

In some areas insect infestation becomes an important consideration in choosing between the various methods of harvesting, conditioning, and storing wet corn.

Extent of insect damage in ear corn and shelled corn stored under varying conditions was studied at the Tidewater Research Station, Holland, Va., in 1953-54 and 1954-55, by ARS and the Virginia State Agricultural Experiment Station. These studies showed that in this warm humid area, storage losses due to insects were much lower for shelled corn (harvested at a high moisture content and stored in steel bins after mechanical drying) than for ear corn stored in open wire bins.

Eight comparable lots of corn--four of shelled corn and four of ear corn--were stored in the 1954-55 storage tests. Each of the comparable lots of ear and shelled corn was harvested and handled before storage in one of four different ways: Some harvested early and some late; some treated with a pesticide and some untreated.

When the corn was unloaded about a year later the shelled corn had lost an average of 0.8 lbs. of dry weight per bushel in storage while comparable ear corn lost 5.1 lbs. per bushel. Damage to shelled corn by weevils and moths increased 3.1 percent while ear-corn damage increased 48.5 percent. All ear corn had been reduced to sample grade when unloaded.

Table 4 shows the weight loss and total insect damage during storage to early- and late-harvested shelled and ear corn, both treated and untreated.

Tests conducted during the 1953-54 season at the Tidewater Research Station also underlined the importance of drying corn to safe levels before storage in order to hold down damage from insects. Results of these corn storage tests indicated that early harvest and drying aids in the reduction of insect injury but early harvest without drying increases damage.

Results of the storage studies at Holland, Va., apply to a warm, humid area in which insect infestation is a particular problem. (Insects get an earlier start and so can cause more damage in warm climates where they are able to survive the mild winter. Also high humidity slows drying and is favorable to insect activity.) However, the finding that insects cause greater damage in corn stored as ear corn than in shelled grain is in line with evidence found by entomologists and grain storage specialists investigating insect damage to stored corn in other areas.

Insect damage is less of a problem with shelled corn than ear corn because it is adaptable to storage in tight bins in which the grain can be fumigated and where it is less accessible to moths.

Table 4--Keeping qualities of shelled and ear corn as affected by harvesting and storage practices, Holland, Va., 1954-55.

Treatment	Pounds		Moisture pct. wet basis		Test wt. lbs. per bu.		Total damage pct.		Corncobs and foreign matter, pct.		Grade		Loss of dry matter, lbs.	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out		
SHELLED CORN														
Early-harvested, dried, untreated	1,798	1,800	12.5	12.6	56.5	56.5	0.8	3.3	1.0	0.7	1	2	0	
Early-harvested, dried, treated with insecticide[1]	1,737	1,695	11.2	11.3	55.0	55.0	1.7	3.8	1.0	1.0	1	2	39	
Late-harvested, treated with insecticide[1]	1,626	1,615	13.0	13.1	55.5	54.5	1.2	2.5	1.0	1.0	1	1	11	
Late-harvested, untreated	1,841	1,795	12.7	12.9	57.0	55.0	---	5.8	.4	.7	1	3	44	
EAR CORN														
													Corn and cobs	Corn
Early-Harvested, dried, untreated	[2]1,899	[2]1,720	12.6	11.3	57.0	51.5	2.9	64.0	---	1.0	1	[3]S	179	144
Early-harvested, dried, treated with insecticide[1]	[2]1,905	[2]1,776	13.6	10.7	56.5	53.0	.5	40.0	---	1.0	1	[3]S	129	95
Late-harvested, treated with insecticide[1]	[2]1,899	[2]1,759	12.5	11.0	56.5	52.0	---	48.0	---	---	1	[3]S	140	108
Late-harvested, untreated	[2]1,850	[2]1,677	12.5	10.6	57.5	53.0	1.2	60.8	---	---	1	[3]S	173	143

[1] The treated corn in every case was dusted with a commercial insecticide containing 0.05 percent pyrethrins and 0.8 percent piperonyl butoxide at a rate to cover the kernels with dust. This was applied to the corn as it moved up a single-chain elevator to the bin.

[2] Reduced to pounds of dry matter in corn and cobs.

[3] Sample.

Animal Feeding Experiments Test Influence of Drying Methods on Feed Value of Corn

Since the largest part of the corn produced for grain eventually is used for feeding animals,[11] the effect of various methods of conditioning and storing wet corn on its nutritional value and palatability is important to growers and buyers of corn.

For a number of years experiments have been underway at the Agricultural Research Center, Beltsville, Md., to test the effect of initial moisture content, drying temperature, and other variables in mechanical drying on the value of the corn for feed. In a series of feeding trials, gains made by rats fed on field-dried corn and corn dried mechanically under varying conditions were compared. (Most of the feeding experiments to date have been done with rats because the tests can be run more cheaply and quickly with the rodents than with larger animals.)

Evidence from the rat feeding experiments, and from more limited swine feeding trials indicate that the nutritional value of wet corn dried mechanically either with heated or unheated air (in accordance with recommended procedures) is equal to field-dried corn. The tests showed that excessive heat can cause damage, however, and that greater food losses occur when corn of high moisture content is subject to heat. Rate of airflow is also an important factor affecting the amount of heat that can be used in drying without causing serious damage, continuing research is showing.

Of the nutritive constituents measured by feed trials and by chemical analysis, protein was found to be the most sensitive to heat. Little loss in energy value was found in grain with drying air up to 173° F. No significant vitamin losses occurred with air temperatures up to 190° F., but at higher temperatures (300° F.) some reduction was noted in the vitamins. (Of the vitamins, Vitamin A appears to be the most susceptible to heat.) Although early studies demonstrated that slow drying with air heated above 135° F. could damage the protein nutritive value of corn, more recent experiments underline the importance of other variables acting in combination with heat and suggest that much higher air temperatures can be used safely provided the airflow is increased sufficiently.

Although corn is often considered principally as a source of energy in livestock feeding, its 8 to 10 percent protein content contributes greatly as a protein source when, as frequently occurs, corn constitutes a high proportion of animal diet.

Recent feeding trials directed particularly at determining the effects of the new harvesting methods of field shelling and drying corn on the protein nutritive value of the grain involved corn samples of various moisture contents dried with air at different temperatures and rates of airflow for various lengths of time. Comparison of gains made by rats fed on the various samples indicated that drying 25-percent moisture corn with air

[11] Of the 1958 crop, only 35 percent was sold off the farm (including deliveries to CCC under the price support program). More than one-half of the corn sold went into feed, either in mixed feed or by direct sale to livestock producers. About 11 percent of the corn sold for grain went to wet millers (for starch, sugar, and sirup), 7 percent to dry millers (for cornmeal, grits, and dry cereal), and 20 percent for alcohol products, seed, export and other purposes.

heated up to 197° F. for 4 hours or less did not reduce the protein nutritive value significantly. The studies also indicated that when the rate of airflow was increased, with a consequent decrease in drying time, corn could be dried with heated air at a higher temperature without damage. For example, corn with an initial moisture content of 29 to 32 percent was dried with air heated to 240° F. and an airflow rate of 110 to 112 cfm/bu. without damage. Air temperatures of 280° F. caused marked brown discoloration, parched corn odor, and losses in protein nutritive value shown by rat assay methods.

DESIGN AND CONSTRUCTION OF DRYING AND STORAGE FACILITIES AND STRUCTURES

Despite radical changes in the production of corn and harvesting methods, which have tended to increase the moisture content of corn at harvest, many of the structures currently used for farm drying and storage of corn were built in the days when the then prevalent hand-harvesting methods were likely to result in more field drying and when earlier maturing corn was generally grown. Farmers can and do change machinery when obsolete equipment wears out. But farmers who have obsolete buildings sometimes feel that they can't afford to replace them.

Even today some new structures for holding grain on the farm are being built along traditional lines that have been largely outdated by recent discoveries and changing practices in the production, harvesting, and handling of grain. A case in point is the drive-in type of crib with overhead storage. ARS research engineers consider this an uneconomic method for handling corn.

Improved Design Data Available

Fortunately for growers who are considering investing in new equipment and buildings for drying and storing corn, experience and research during the last quarter of a century have resulted in a great, although gradual improvement in design. Only the manufacturer and builder have to be concerned with the mass of technical data on which new design of equipment and facilities will be based. But individual corngrowers need to know some basic principles that have been developed to be in a position to benefit from new design and to avoid costly building mistakes.

Allowing For Building Strain

When buildings are built or adapted for conditioning or storing high-moisture corn, it is important to allow for any additional building strain involved. Otherwise costly building failure and loss of the grain may result.

If a structure designed for storing or drying ear corn is used for shelled corn, usually it will be necessary either to strengthen the walls and foundation or to reduce the volume of grain stored. Similarly, structures built for grass silage are likely to need strengthening if used for wet storage of an equal volume of heavier ground ear corn or shelled grain.

A similar type of problem arises when corn is dried to a safe moisture content for storage (to 13 percent or less) and then is permitted to reabsorb moisture from the air. Since grain expands and increases in weight as it absorbs moisture, this process increases the strain on the building.

Most farmers now dry their corn to the level at which they use or dispose of it. But any system of over-drying and rewetting the corn to make it more palatable for livestock or to restore it to standard moisture content for marketing would probably involve redesign of buildings or strengthening of old ones to withstand the added strain.

Basis for Estimating Relative Efficiency of Perforated-Floor and Duct Systems Developed

One major question facing the designer and builder of a structure for in-storage drying with unheated air is whether a perforated-floor or duct type of system would be better in a particular instance.

Perforated-floor, parallel-flow systems circulate the air more evenly through the grain and so make more efficient use of fanpower than do duct systems. But perforated-floor systems are more expensive to build and more difficult to clean and to load and unload. Which type would be the better drier for the money in a particular case depends, to a large degree, on whether the cost of building the duct system and of cleaning, loading, and unloading it is enough <u>less</u> to make up for the loss in ventilation efficiency.

As a result of studies of grain ventilation and drying patterns conducted by ARS research engineers in cooperation with the Iowa State Agricultural Experiment Station, a formula has been developed for calculating precisely the relative efficiency of duct and perforated-floor systems built to particular measurements. In general, the greater the width of the grain to be dried between the ducts, the greater the loss in efficiency.

Some Considerations In Converting Cribs to Mechanical Drying

Farmers considering changing to mechanical drying are sometimes interested in the possibilities of converting old cribs or bins for in-storage drying by forced ventilation. ARS engineers point out that, while this may sometimes be done advantageously, the cost of adapting unsuitable buildings might in other cases be more advantageously invested in a new drier of efficient, modern design.

Whereas heated-air driers on farms 5 or 10 years ago usually consisted of a furnace and a fan attached to a bin, the present trend--as observed by ARS engineers in the Corn Belt--is away from the farm-built drier toward purchase of drying equipment designed and sold as single units of varying capacity and price ranges.

For the farmer who is not ready to switch to mechanical drying but wants to put up a permanent structure for drying his corn by natural ventilation, ARS recommends that the crib be built with closed ends in a design suitable for in-storage drying with forced air. This would enable the grower to make a quick and successful changeover to mechanical drying by installation of ducts and a blower in a wet-year emergency.

RESEARCH PROSPECTS

The basic general principles and equipment necessary for doing a good job of harvesting, conditioning, and storing wet corn have been developed through research in recent decades. From the vantage point of current scientific and technological progress, research can now move in the direction of developing more refined methods and machinery to cut costs of harvesting and handling wet corn while maintaining its quality. To this end, the search for more complete, quantitative information about the effect of different variables--such as initial moisture content, mechanical damage, and temperature--on the keeping quality of corn is continuing.

A case in point is research aimed at yielding more information about the effect of mechanical damage on the keeping quality of corn: (1) To determine how mechanical damage to the kernel increases mold invasion; and (2) to measure the changes that take place in damaged corn during storage. Such information would give designers and manufacturers of harvesting equipment more precise data on which to strike a balance between cost and precision required to avoid mechanical damage above tolerance levels for safe storage.

Similarly, because of the important relationship between climate and economic design for unheated-air driers, the practicality of making weather data of various corn-growing areas available in a form more usable by drier designers and builders is being studied. Data on average weather conditions in a number of corn-growing States is being compiled in terms of monthly wet-bulb depressions and their variations. (Wet-bulb depression is a measure of drying capacity of natural air used in calculating the time required for drying a given quantity of grain.[12]) The aim of this project is to reduce complex wet-bulb weather data of the States needing it for drier design to a form simple enough to be readily used. This would enable manufacturers and builders to custom design their drying equipment to meet the particular needs of the area for which it is built.

These are only a few examples of fundamental and applied research directed at getting more complete and better answers to problems connected with wet corn. The major responsibility lies in the field of engineering research but problems related to wet corn are being attacked on a wide front. In developing new varieties of corn, plant breeders look for varieties that are adapted to mechanical harvesting and are resistant to insect damage. Entomologists are constantly searching for better ways to control pests attacking grain in the field and in storage. As in the past, scientists of ARS and a number of State agricultural experiment stations are working with farmers, farm machinery and building designers and manufacturers, and other interested groups on possibilities and problems connected with high-moisture corn.

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[12] To make the wet-bulb depression readings, two thermometers are used: one dry thermometer and one thermometer that is kept wet. Since the process of evaporation reduces temperature, the temperature of the thermometer with the wet bulb will be reduced in proportion to the rate at which water evaporates from it into the surrounding air. Thus the difference in temperature between the wet-bulb thermometer and the dry thermometer is a measure of the rate of evaporation--and so, indirectly, a measure of the drying capacity of the surrounding air.

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